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Mixing Ratio of Peat Moss, Coco Peat, and Perlite Affects the Physicochemical Properties of Media and Growth of *Tetragonia tetragonioides*

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Abstract

The goal of this study was to select the most suitable medium for the cultivation of New Zealand spinach in a greenhouse. After sowing and raising seedlings, the seedlings were transplanted in media at mixing ratios of 4:0:0, 3:0:1, 3:1:0, 2:0:2, 2:1:2, 2:2:0, 1:0:3, 1:1:2, 1:2:1, 1:3:0, 0:0:4, 0:1:3, 0:2:2, 0:3:1, and 0:0:4 (v/v) composed of peat moss, coco peat, and perlite. After harvesting the shoots and roots, the shoot growth, fresh weight, and dry weight were measured and the nutrient contents of the leaves and physicochemical properties of the media were analyzed. The shoot growth metrics of the main stem length, number of lateral branches, and leaf size were better in media with mixing ratios of 2:2:1, 2:2:0, and 1:3:0 compared to the other ratios. Also, the fresh and dry weights of the leaves, stems, and roots were heaviest in media when the mixing ratio was 1:3:0. The air phase, porosity and water content of coco peat were higher than those of peat moss and perlite, and media with a high mixing ratio of coco peat (0:4:0, 0:3:1, 1:3:0) had higher EC and mineral contents (P, K, and B) than media with a high mixing ratio of perlite; moreover, the leaves grown in these media had higher nutrient contents, such as K and Ca. Therefore, considering the shoot growth and fresh and dry weights of the leaves, stems and roots in New Zealand spinach, it was determined that cultivation in a medium with a mixing ratio of 1:3:0 of peat moss, coco peat, and perlite would be most effective.

Additional key words: mineral contents, new zealand spinach, nutrient contents, porosity, water content

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Introduction

Tetragonia tetragonioides (Pall.) Kuntze is a perennial herb belonging to the Aizoaceae family, commonly referred to as New Zealand spinach. Its leaves are fleshy, branches grow sideways from the main stem and it is known as a halophyte (Lee et al., 2008). It is distributed in Korea, China, Japan, South Asia, Australia, New Zealand and South America. In Korea, it grows in the coastal areas of the central and southern parts of the country or in sandy ground or rock crevices on the seashore in

Shinan-gun, Jeju Island, Ulleungdo and Dokdo (Gray, 1997; Kim et al., 2008).

New Zealand spinach has been known as a medicinal herb for the stomach since ancient times and has been used to treat gastric diseases such as gastric cancer, gastritis, gastric ulcer, and hyperacidity (Kato et al., 1985). It is also reportedly effective for diabetes prevention and as an anti-inflammatory, anti-ulcer and antioxidation treatment (Lee et al., 2008; Choi et al., 2015, 2017). In addition, the leaves of New Zealand spinach can be used for salads or as a vegetable for wraps, seasoned vegetable dishes or soups, and as an ingredient in Kimchi (Haase, 1990; Jaworska, 2005). In this way, New Zealand spinach can be used for various purposes, i.e., food and medicine, but surprisingly there is little research on its cultivation, except for studies that investigated the growth of New Zealand spinach on seashore and upland areas and in paddy soil (Kim et al., 2011; Lee and Kim, 2021).

Horticulture substrates are composed of materials with physical, chemical, and biological properties suitable for crop cultivation, supplying various nutrients and moisture necessary for crop growth while mechanically supporting plants (Kim and Ahn, 2002; Jang et al., 2022). The raw materials for horticultural media are mainly organic materials such as coco peat and peat moss along with inorganic materials such as perlite and vermiculite. Peat moss is formed by the long-term carbonization of sphagnum moss and silver grass deposited in wetlands in oxygen-deficient soil, and it contains more than 90% organic matter (Lee et al., 2006; Kim and Kim, 2011). The available moisture content of peat moss is 55%; it has a good water-holding capacity, but air permeability and drainage are not good, and these factors occasionally interfere with plant growth (Bilderback et al., 1982; Dole and Wilkins, 1999). Coco peat is made from coconut husks, referring to the shell tissue of coconut fruit, and it is widely used as an organic material in Korea because prices are typically reasonable. The important characteristics of coco peat are its excellent air permeability, water-holding capacity, nutrient-holding capacity, low bulk density, high cation exchange capacity, and high expansion up to four to five times in volume when mixed with water (Kim, 2003; Kim et al., 2021). Perlite is made by crushing larger perlite pieces and then baking and expanding them at a temperature of approximately 1000°C. It is light in weight and has high air permeability due to its porosity, but the water-holding capacity of the coarse-grained type of perlite is poor (Wilson, 1985; Shim et al., 2016).

A single material is occasionally used as a medium for the cultivation of horticultural crops, but most media use a mixture of two to three material types to supplement and control the physical and chemical properties of the materials. The plant height, internode length, and root length of *Veronica rotunda* var. *subintegra*, a plant endemic to Korea, was better in media with a mixing ratio of 2:1 of clay sand and peat moss (Lee et al., 2020). It was reported that *Delosperma cooperi* grew well in media mixed with vermiculite and a fertilizer-amended medium, for which the water- and nutrient holding-capacities were good (Lee et al., 2022). Tuber enlargement and shoot growth of *Pinellia ternata* (Thunb.) Breit were most effective when grown in media with a mixing ratio of 54:12:2:27:5 of coco peat, peat moss, vermiculite, perlite and zeolite; these results were attributed to the characteristics of *P. ternata*, which grows well in soil with good drainage (Lee et al., 2017). It has also been reported that *Salicornia herbacea*, a halophyte inhabiting coastal areas, when planted in soils mixed with porous mudball and perlite materials, grows well in terms of the plant height, fresh weight and dry weight (Baik and Chiang, 2011).

In this way, suitable medium conditions are different for each plant based on the characteristics of the plant. Therefore, it is necessary to identify the best medium conditions for growth. Accordingly, in this study, in an effort to determine the appropriate medium conditions for cultivating New Zealand spinach, peat moss, coco peat, and perlite were tested at different mixing ratios and the growth and physicochemical properties of these media samples were investigated.

Materials and Methods

Plant Materials

This experiment was conducted in a greenhouse on a research farm at Mokpo National University. New Zealand spinach seeds were sown in 50-cell plug trays filled with a horticultural medium (Biosangto®, Heungnong, Co., Ltd., Seosan, Korea) on April 16, 2017, and seedlings with four developed leaves (plant height 6.2 ± 0.3 cm, fresh weight of stem 2.2 ± 0.3 g, fresh weight of root 0.2 ± 0.1 g) were used as the materials for the experiment on June 2, 2017.

Growth according to the Mixing Ratio of Peat Moss, Coco Peat, and Perlite

To investigate the growth of New Zealand spinach according to the composition of the medium, peat moss (Particle size: extra-fine 0 − 6 mm, Lithuanian Peat Moss, Klasmann-Deilmann GmbH, Germany), coco peat (Particle size: 0.5 − 3 mm, imported from India, Shinsung Mineral Co., Ltd. Jincheon, Korea), and perlite (1 − 5 mm in diameter, Parat No. 1, Kyungdongone Co., Ltd., Korea) were mixed at ratios of 4:0:0, 3:0:1, 3:1:0, 2:0:2, 2:1:1, 2:2;0, 1:0:3, 1:1:2, 1:2:1, 1:3:0, 0:0:4, 0:1:3, 0:2:2, 0:3:1, and 0:4:0 (Table 1). Seedlings were transplanted into black nonwoven fabric pots (diameter 60 cm, height 40 cm) filled with 80 L of the mixed media on June 2,2017. There were seven plants per treatment, and all pots were completely randomized in the greenhouse during the experiment.

For fertilization, 25 kg of nitrogen, 5.9 kg of phosphorus, and 11.9 kg of potassium per 10a were treated with urea (Namhae Chemical Corp. Yeosu, Korea), Yonggwalin (fused superphosphate, KG Chemical Co., Ltd., Sungnam, Korea), and potassium chloride (Namhae Chemical Corp. Yeosu, Korea), respectively, by referring to the standard fertilization

Table 1. Shoot growth according to the mixing ratio of peat moss, coco peat, and perlite 64 days after transplanting New Zealand spinach plants

Media (PT : CP : PL)[z]	Length of main stem (cm)	Length of lateral branch (cm)	No. of lateral branches (ea)	Leaf length (cm)	Leaf width (cm)
4 : 0 : 0	80 de[y]	77 c	15.2 e	10.1 cd	7.4 cd
3 : 0 : 1	82 de	95 bc	16.0 e	10.5 cd	8.1 cd
3 : 1 : 0	115 a	122 a	22.0 bc	13.6 a	11.2 a
2 : 0 : 2	87 cde	101 bc	17.6 de	10.9 cd	8.3 cd
2 : 1 : 1	116 a	128 a	24.6 a	13.5 a	10.4 ab
2 : 2 : 0	109 ab	121 a	24.6 a	12.7 ab	9.6 bc
1 : 0 : 3	89 bcd	82 c	16.6 e	12.2 bc	9.5 bc
1 : 1 : 2	98 bc	113 ab	22.0 bc	12.7 ab	10.0 ab
1 : 2 : 1	99 bc	119 ab	24.6 a	12.1 bc	9.1 bcd
1 : 3 : 0	102 ab	121 a	25.6 a	11.4 bcd	8.5 cd
0 : 0 : 4	43 f	36 d	6.4 f	9.8 d	7.2 d
0 : 1 : 3	71 e	76 c	14.8 e	11.5 bcd	8.7 cd
0 : 2 : 2	69 e	81 c	16.8 de	12.5 bc	9.2 bc
0 : 3 : 1	90 bcd	100 bc	18.6 de	13.7 a	10.3 ab
0 : 4 : 0	100 bc	112 ab	21.0 cd	13.5 a	10.1 ab

[z]PT: peat moss, CP: coco peat, PL: perlite.

[y]Mean separation within columns according to Duncan's multiple range test at the $p < 0.05$ level.

rate of spinach of the Rural Development Administration, as there was no standard fertilization amount for New Zealand spinach (RDA, 2006). In addition, 100% of Yonggwalin and 50% of nitrogen and potassium were applied as basal fertilizers, and 50% of nitrogen and potassium were applied as additional fertilizers 30 days after planting. Irrigation was conducted by using a sprinkler for 30 minutes at 2-day intervals.

New Zealand spinach was harvested 64 days after planting, and the lengths of the main stem and lateral branches, the number of lateral branches, the leaf length, the leaf width, and the fresh and dry weights of leaves, stems and roots were measured. The length of the main stem was measured from the surface of the medium to the top of the stem. The number of lateral branches was calculated by counting the branches that grew more than 10 cm at the node, and the length of the lateral branches was measured from the node of the main stem to the end of the branch. Leaf length and width were measured by selecting the largest leaf. The harvested New Zealand spinach was separated into leaves, stems, and roots to measure the fresh weight, and the dry weight was investigated after drying the leaves, stems, and roots at 75°C for three days.

Analysis of Physicochemical Properties of Media and Nutrient Contents of Leaf Tissue

After measuring the growth of the New Zealand spinach, three pots per treatment were selected and the physicochemical properties of the media and nutrient contents of the leaf tissue then were analyzed in triplicate. The analysis of the physical properties of the media, such as the three phase ratios, bulk density, porosity and moisture content, was conducted according to the standard analysis method of soil by the Rural Development Administration (RDA, 2002). In order to analyze the chemical properties of the media, the media were sampled from a portion 10 − 20 cm below the media surface, with air-drying indoors for two weeks. For the leaf tissue analysis, leaves in the middle of the stem were collected, dried at 75°C for three days, and then finely ground with a grinder. For a nutrient analysis of the media and leaves, samples were sent to J.R. Peters Laboratory (Allentown, PA, USA). Among the inorganic elements, P, K, Ca, Mg, S, B, Fe, Cu, and Zn were analyzed using ICP-OES (inductively coupled plasma-optical emission spectrometry) (Thermo Jarrell Ash, Corp., Franklin, MA, USA), and nitrate-nitrogen and ammonium-nitrogen contents were analyzed using a SAN++ segmented flow analyzer (Skalar Inc., Buford, GA, USA). The suggested ranges for the pH, EC, and nutrients of the media or leaf tissues are data established by J.R. Peters Inc. (Yoo et al., 2017).

Data Analysis

Data on the shoot growth, fresh and dry weights of the plants, the physicochemical properties of the media, and the nutrient contents of the leaf tissues were subjected to an analysis of variance using IBM SPSS Statistics for Windows (Version 22.0 software, IBM Corp., 2019). All means were compared using Duncan's multiple range test at $p < 0.05$.

Results

Growth according to Mixing Ratio of Peat Moss, Coco Peat, and Perlite

The seedlings of New Zealand spinach were planted in media according to the mixing ratios of the peat moss, coco peat and perlite, and the growth outcomes were investigated after 64 days (Table 1). The main stem was longer in the media

with mixing ratios of 2:1:1, 3:1:0, 2:2:0, and 1:3:0 (102 cm) with peat moss, coco peat, and perlite than in the other media. In the media with mixing ratios of 0:0:4, 0:1:3 and 0:2:2, the main stem length was shorter than 71 cm. The lateral branch length exceeded 121 cm in the media with mixing ratios of 2:1:1, 3:1:0, 2:2:0 and 1:3:0 with peat moss, coco peat, and perlite, and in the media with mixing ratios of 4:0:0, 0:0:4, 0:1:3 and 0:2:2, it was shorter than 81 cm. The number of lateral branches was as high as 25 in the media with mixing ratios of 1:3:0, 1:2:1, 2:1:1, and 2:2:0, and in the media with mixing ratios of 4:0:0, 1:0:3, 0:0:4, and 0:1:3, there were fewer than 16.6 lateral branches. The leaf length was longer in the media with the mixing ratios of 3:1:0, 2:1:1, 0:3:1 and 0:4:0 (13.5 − 13.7 cm) compared to those in the other media, and it was shortest in the 0:0:4 medium, i.e., 100% perlite. The leaf width was longest at 11.2 cm in the 3:1:0 medium and the shortest at 7.2 cm in the 0:0:4 medium. In general, growth was poor in media with 100% peat moss or perlite (4:0:0 or 0:0:4) and in media with mixing ratios of 3:0:1, 2:0:2, and 1:0:3 with peat moss and perlite. Also, growth was poor in media with mixing ratios of 0:1:3 and 0:2:2, where coco peat was mixed with perlite at a rate exceeding 50%. On the other hand, the growth levels of stems and lateral branches were found to be good in media with mixing ratios of 2:1:1, 2:2:0 and 1:3:0 with peat moss, coco peat and perlite (Fig. 1).

The fresh weight of the leaves was heavier in the medium with the mixing ratio of 1:3:0 (1,835 g) with peat moss, coco peat and perlite compared to those in the other media, whereas it was lightest at 61 − 138 g in the media with mixing ratios of 4:0:0 with 100% peat moss and 0:0:4 with 100% perlite (Table 2). The dry weight of the leaves also showed results similar to those of the fresh weight. The fresh and dry weights of the stems were heaviest at 1,355 g and 121 g, respectively, in the medium with a mixing ratio of 1:3:0 and was lighter in the media with mixing ratios of 0:0:4, 4:0:0, 0:1:3, 2:0:2, 3:0:1, 0:2:2, 1:0:3 and 0:3:1 compared to the others. The fresh and dry weights of the roots were heavier at 31.5 − 38.2 g and 4.3 − 4.7 g, respectively, in the media with mixing ratios of 2:1:1, 1:3:0 and 2:2:0 compared to the other

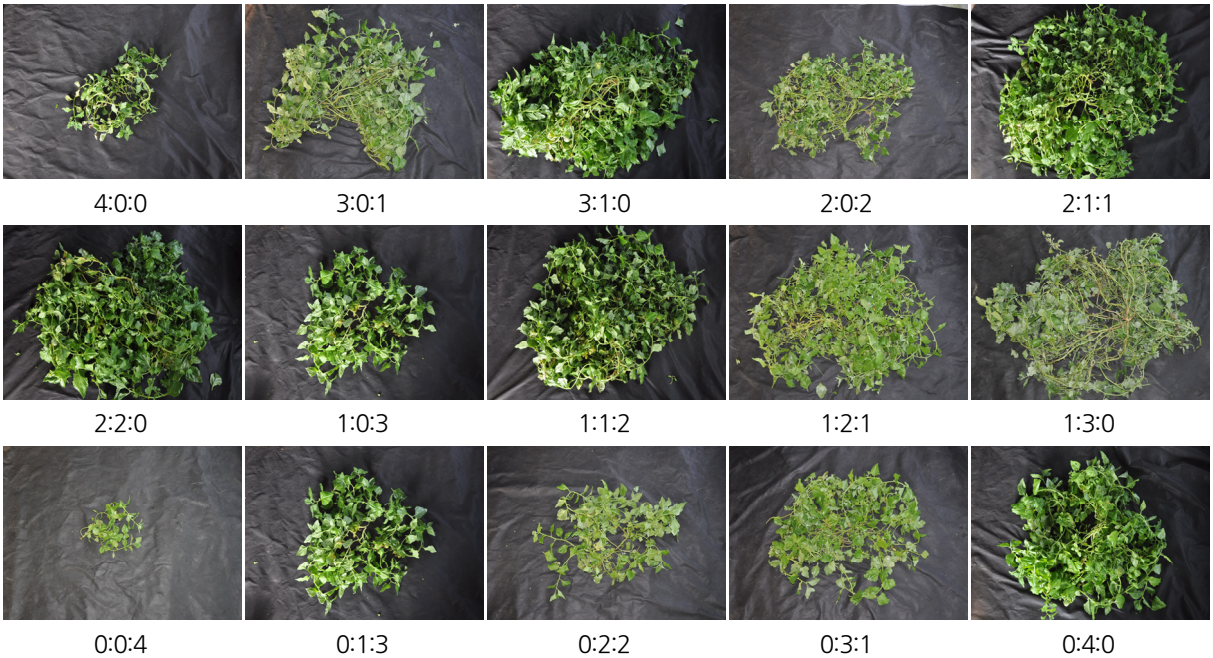

Fig. 1. Appearance of shoots according to the mixing ratio of peat moss, coco peat, and perlite 64 days after transplanting New Zealand spinach plants.

Table 2. Fresh and dry weights of leaves, stems, and roots according to the mixing ratio of peat moss, coco peat, and perlite 64 days after transplanting New Zealand spinach plants

Media (PT : CP : PL)[z]	Leaf		Stem		Root	
	Fresh weight (g)	Dry weight (g)	Fresh weight (g)	Dry weight (g)	Fresh weight (g)	Dry weight (g)
4 : 0 : 0	138 f[y]	11 ef	151 gh	11 gh	4.0 e	0.6 e
3 : 0 : 1	442 e	30 de	391 f	30 fg	12.6 cde	1.2 cde
3 : 1 : 0	1,275 bc	88 b	1,240 b	95 b	21.3 b	2.5 c
2 : 0 : 2	370 ef	33 de	448 ef	31 fg	13.3 cd	1.4 cd
2 : 1 : 1	1,123 bc	86 b	1,245 b	91 b	38.2 a	4.7 a
2 : 2 : 0	1,372 b	86 b	1,238 b	99 b	31.5 a	4.3 a
1 : 0 : 3	522 e	28 de	389 f	21 fg	6.2 de	0.6 e
1 : 1 : 2	1,163 bc	70 bc	890 c	68 d	22.9 b	2.7 b
1 : 2 : 1	1,250 bc	88 b	1,172 b	84 c	19.2 bc	2.7 b
1 : 3 : 0	1,835 a	113 a	1,355 a	121 a	32.5 a	4.6 a
0 : 0 : 4	61 f	4 f	35 h	3 h	1.5 e	0.1 e
0 : 1 : 3	409 e	22 def	550 de	14 gh	6.1 de	1.2 cde
0 : 2 : 2	531 e	29 de	296 fg	17 gh	4.7 e	0.3 e
0 : 3 : 1	855 cd	50 cd	545 de	39 ef	5.6 e	0.9 de
0 : 4 : 0	982 c	61 c	781 c	62 d	13.0 cd	1.5 cd

[z]PT: peat moss, CP: coco peat, PL: perlite.

[y]Mean separation within columns according to Duncan's multiple range test at the $p < 0.05$ level.

media types and were light in the media with mixing ratios of 0:0:4, 4:0:0, 1:0:3, 0:3:1, 0:2:2 and 0:1:3. Overall, the fresh and dry weights of the leaves, stems and roots of the New Zealand spinach were heaviest in the medium with a mixing ratio of 1:3:0 and were light in the media with mixing ratios of 4:0:0, 3:0:1, 2:0:2, 1:0:3, 0:0:4, 0:1:3 and 0:2:2 with peat moss, coco peat and perlite .

Physicochemical Properties of the Media and Nutrient Contents of Leaf Tissue according to the Mixing Ratio of Peat Moss, Coco Peat, and Perlite

Physical properties of media

The results of the analysis of the physical properties of the media according to the mixing ratios of peat moss, coco peat, and perlite are presented in Table 3. In the three phases of media, the ratios of the solid (47.1 − 53.1%) and liquid phase (10.0 − 12.0%) were higher in the media with mixing ratios of 1:0:3, 4:0:0, 3:0:1, 2:0:2, 0:0:4 and 0:1:3, with high peat moss and perlite contents. On the other hand, the ratio of the air phase was higher in the media with mixing ratios of 1:2:1 (58.5%). 1:3:0 (59.4%) and 0:4:0 (57.4%) with a high coco peat content compared to the media with mixing ratios of 1:0:3, 4:0:0, 3:0:1, 2:0:2, 0:0:4, 0:1:3 and 0:0:2 (34.9 − 45.1%). The bulk density was lower in the 1:3:0 and 0:4:0 media with a high mixing ratio of coco peat than in the media with mixing ratios of 1:0:3, 0:0:4, 3:0:1, 2:0:2, 1:1:2 and 0:1:3, where the ratios of the solid phase and liquid phase were high. The porosity was as high as 62.8 − 65.9% in the media with mixing ratios of 1:2:1, 1:3:0, 2:1:1 and 0:4:0 and was low in the media with mixing ratios of 4:0:0, 3:0:1, 2:0:2, 1:0:3, 0:0:4 and 0:1:3, where the ratios of peat moss and perlite were high. The moisture content was higher in the media with

Table 3. Physical properties of media with different mixing ratios of peat moss, coco peat, and perlite 64 days after transplanting New Zealand spinach plants

Media (PT : CP : PL)[z]	Three phase (%)			Bulk density ($g \cdot cm^{-3}$)	Porosity (%)	Moisture content (%)
	Solid	Liquid	Air			
4 : 0 : 0	51.9 ab[y]	10.0 ab	38.1 cd	0.14 bc	48.2 cd	73.7 bc
3 : 0 : 1	47.2 ab	10.3 ab	42.5 bc	0.15 ab	52.7 cd	68.0 cde
3 : 1 : 0	40.3 bcd	7.8 bc	51.9 ab	0.11 c	59.8 bc	73.3 bc
2 : 0 : 2	48.0 ab	10.6 ab	41.4 bc	0.16 ab	52.2 cd	66.6 de
2 : 1 : 1	37.7 cd	8.2 bc	54.1 ab	0.13 bc	62.9 ab	76.6 b
2 : 2 : 0	42.8 bc	7.4 cd	49.8 abc	0.10 c	57.2 bc	77.7 b
1 : 0 : 3	53.1 a	12.0 a	34.9 d	0.19 a	46.9 d	65.3 de
1 : 1 : 2	42.9 b	9.6 b	47.5 abc	0.15 ab	57.1 bc	64.1 de
1 : 2 : 1	34.2 d	7.4 cd	58.5 a	0.12 bc	65.9 a	66.6 de
1 : 3 : 0	35.1 d	5.5 d	59.4 a	0.07 d	64.9 a	80.4 a
0 : 0 : 4	48.2 ab	10.5 ab	45.1 bc	0.18 a	52.6 cd	61.2 e
0 : 1 : 3	47.1 ab	10.3 ab	42.6 bc	0.16 ab	52.9 cd	67.5 de
0 : 2 : 2	44.4 b	9.8 b	42.0 bc	0.14 bc	55.8 c	71.7 bcd
0 : 3 : 1	40.7 bcd	7.7 bc	51.6 ab	0.10 cd	59.4 bc	74.8 b
0 : 4 : 0	37.2 cd	5.4 d	57.4 a	0.07 d	62.8 ab	82.2 a

[z]PT: peat moss, CP: coco peat, PL: perlite.

[y]Mean separation within columns according to Duncan's multiple range test at the $p < 0.05$ level.

mixing ratios of 0:4:0 and 1:3:0 (80.0 − 82.2%) than in the other media samples, and it was lowest in the 0:0:4 medium with 100% perlite. Overall, in the media with high mixing ratios of peat moss and perlite, where the ratios of the solid and liquid phase were high, the bulk density was high and the moisture content was low. On the other hand, in the media with high mixing ratios of coco peat, the air phase ratio and the moisture content were high and the bulk density was low.

Chemical properties of the media

The results of the analysis of the chemical properties of the media according to the mixing ratio of peat moss, coco peat, and perlite medium are presented in Table 4. The pH was lowest in the medium with 100% peat moss (4.0) and was higher in the media with mixing ratios of 0:0:4, 0:1:3 and 0:2:2 (6.2 − 6.9), where the ratio of perlite was high. The EC was highest at 0.93 $dS \cdot m^{-1}$ in the 1:3:0 medium and decreased in general as the ratio of perlite was increased. The nitrate-nitrogen content was higher in the media with mixing ratios of 1:3:0 and 2:0:2 (37.0 − 38.3 $mg \cdot kg^{-1}$) than in the other media types and was lowest at 6.7 − 7.9$mg \cdot kg^{-1}$ in the media with mixing ratios of 0:0:4, 0:1:3 and 0:2:2. The ammonium-nitrogen content was higher in the 2:0:2 and 4:0:0 media (24.5 − 28.5 $mg \cdot kg^{-1}$) and was low at 0.4 − 0.8$mg \cdot kg^{-1}$ in the media with mixing ratios of 0:0:4, 0:1:3, 0:2:2, 0:3:1 and 0:4:0, composed without peat moss. The phosphorus content was higher in the media with mixing ratios of 1:3:0 and 2:2:0 (8.9 − 11.7 $mg \cdot kg^{-1}$) than in media with mixing ratios of 0:0:4, 1:0:3, 0:1:3 and 0:2:2 (0.7 − 3.0 $mg \cdot kg^{-1}$), with a high ratio of perlite. The potassium content was higher at 126.1 − 179.9 $mg \cdot kg^{-1}$ in the 0:4:0, 1:3:0 and 0:3:1 media samples with a high ratio of coco peat than in the 0:0:4, 3:0:1 and 0:1:3 media samples with high ratios of peat moss and perlite. The contents of calcium, magnesium, sulfur and zinc were lower than the corresponding suggested ranges in all treatments (Table 4). The boron content was highest at

Table 4. Chemical properties of media with different mixing ratios of peat moss, coco peat, and perlite 64 days after transplanting New Zealand spinach plants

Media (PT:CP:PL)[z]	pH	EC ($dS \cdot m^{-1}$)	Macro-element ($mg \cdot kg^{-1}$)							Micro-element ($mg \cdot kg^{-1}$)			
			NO_3-N	NH_4-N	P	K	Ca	Mg	S	B	Fe	Cu	Zn
4 : 0 : 0	4.0 e[y]	0.54 bc	19.5 bc	24.5 a	7.6 bc	37.1 de	8.5 a	2.9 ab	8.0 a	0.02 d	0.41 a	0.03 a	0.03 ab
3 : 0 : 1	4.2 de	0.52 cd	13.3 c	13.5 bc	5.3 bcd	23.8 e	4.9 ab	1.6 b	4.5 ab	0.01 d	0.25 ab	0.03 a	0.01 b
3 : 1 : 0	3.9 e	0.61 bc	22.2 bc	20.8 ab	5.8 bcd	66.5 cd	11.3 a	5.3 a	9.7 a	0.08 bc	0.36 ab	0.04 a	0.03 ab
2 : 0 : 2	4.1 e	0.51 cd	37.0 a	28.5 a	4.5 cd	52.2 d	7.8 a	2.6 b	7.0 a	0.00 d	0.22 ab	0.03 a	0.02 b
2 : 1 : 1	4.2 de	0.46 cd	12.6 c	6.9 cd	5.2 bcd	45.6 d	7.2 a	3.2 ab	5.9 ab	0.07 c	0.34 ab	0.02 a	0.01 b
2 : 2 : 0	4.3 de	0.56 bc	19.1 bc	7.0 cd	8.9 ab	89.5 bc	7.1 a	3.6 ab	7.1 a	0.15 ab	0.42 a	0.02 a	0.03 ab
1 : 0 : 3	5.4 bc	0.43 cd	25.3 bc	9.4 cd	2.7 de	36.8 de	4.8 ab	1.7 b	4.3 ab	0.00 d	0.15 b	0.02 a	0.01 b
1 : 1 : 2	4.6 cd	0.55 bc	25.5 bc	5.3 cd	4.9 cd	67.3 cd	3.7 ab	2.0 b	4.6 ab	0.07 c	0.28 ab	0.02 a	0.02 ab
1 : 2 : 1	5.2 c	0.44 cd	12.2 c	2.1 de	5.3 bcd	79.4 bc	2.7 ab	1.4 b	4.8 ab	0.13 b	0.32 ab	0.02 a	0.03 ab
1 : 3 : 0	5.0 c	0.93 a	38.3 a	4.9 cd	11.7 a	179.9 a	4.8 ab	3.5 ab	7.8 a	0.20 a	0.33 ab	0.02 a	0.07 a
0 : 0 : 4	6.9 a	0.09 e	7.9 d	0.4 e	0.7 e	0.9 f	0.9 b	1.3 b	2.3 b	0.00 d	0.04 c	0.00 a	0.00 b
0 : 1 : 3	6.2 b	0.16 de	7.1 d	0.4 e	1.0 e	24.9 e	0.6 b	0.2 b	1.8 b	0.06 c	0.10 bc	0.01 a	0.00 b
0 : 2 : 2	6.2 b	0.31 d	6.7 d	0.3 e	3.0 de	55.3 d	1.0 b	0.6 b	2.8 b	0.09 bc	0.12 bc	0.01 a	0.00 b
0 : 3 : 1	5.9 bc	0.61 bc	10.9 cd	0.7 e	5.2 bcd	126.1 ab	1.8 b	1.4 b	3.6 ab	0.16 ab	0.16 b	0.03 a	0.01 b
0 : 4 : 0	6.0 bc	0.60 bc	17.8 bc	0.8 e	5.0 bcd	138.3 ab	1.6 b	1.3 b	3.6 ab	0.18 a	0.21 ab	0.02 a	0.00 b
Suggested range[x]	5.2–6.3	0.75–3.5	35–180	5–20	5–50	35–300	40–200	20–100	15–250	0.05–0.5	0.3–3.0	0.01–0.5	0.3–3.0

[z]PT: peat moss, CP: coco peat, PL: perlite.

[y]Mean separation within columns according to Duncan's multiple range test at the $p < 0.05$ level.

[x]Suggested ranges by JR Peters Inc. (Allentown, PA, USA) for general horticultural crops.

0.18 − 0.20 $mg \cdot kg^{-1}$ in the media with 0:4:0 and 1:3:0 ratios, which had a high ratio of coco peat, and it was as low as 0.00 − 0.02 $mg \cdot kg^{-1}$ in the media with ratios of 4:0:0, 3:0:1, 2:0:2, 1:0:3 and 0:0:4, with relatively high ratios of peat moss and perlite. The iron content was lowest at 0.04 $mg \cdot kg^{-1}$ in the 0:0:4 medium composed of 100% perlite.

Nutrient contents of leaf tissue

The results of analyzing the nutrient contents of leaf tissue grown in the media according to the mixing ratio of peat moss, coco peat, and perlite are shown in Table 5. The nitrogen content in the leaf tissue of plants grown in media with mixing ratios of 4:0:0, 0:0:4 and 3:0:1 with peat moss, coco peat, and perlite was significantly higher at 5.6 − 6.2% relative to the suggested range (3.5 − 5.5%). The phosphorus content was low at 0.34 − 0.49% in leaf tissue grown in media with mixing ratios of 0:0:4, 0:2:2 and 0:1:3 with a high ratio of perlite and was within the suggested range (0.35 − 1.0%) in all media types except for the 100% perlite medium (0.34%). The potassium content was within the suggested range (2.0 − 8.0%) in all media samples except for the 1:0:3 medium (1.7%). The calcium content was highest at 1.15% in leaf tissue grown in the medium with a mixing ratio of 1:3:0 and was lower than the suggested range (0.8 − 3.0%) in the media with mixing ratios of 0:0:4, 0:1:3 and 0:2:2. The magnesium content was highest at 0.61% in leaf tissue grown in the 100% peat moss medium, and it was within the suggested range (0.2 − 1.5%) in all media types. The sulfur content was lowest at 0.15 − 0.16% in leaf tissue grown in the media with mixing ratios of 0:0:4, 0:1:3 0:2:2 and 0:3:1, which was lower than the

Table 5. Nutrient contents in leaves grown in media with different mixing ratios of peat moss, coco peat, and perlite 64 days after transplanting New Zealand spinach plants

Media (PT:CP:PL)[z]	Macronutrients (%)						Micronutrients (mg·kg^{-1})			
	N	P	K	Ca	Mg	S	B	Fe	Mn	Zn
4 : 0 : 0	6.2 a[y]	0.68 a	2.5 de	0.86 bc	0.61 a	0.18 cd	15.9 c	119 ab	286 bc	70 abc
3 : 0 : 1	5.6 ab	0.65 a	3.0 cd	0.90 bc	0.56 ab	0.20 bc	22.1 bc	97 cd	253 bcd	68 abc
3 : 1 : 0	5.1 bc	0.61 ab	2.8 de	0.94 b	0.54 bc	0.23 ab	22.3 bc	92 de	332 ab	77 abc
2 : 0 : 2	5.2 bc	0.67 a	3.1 cd	0.90 bc	0.53 bc	0.23 ab	22.3 bc	103 bc	264 bc	105 a
2 : 1 : 1	4.8 cd	0.50 bc	3.7 bc	0.92 bc	0.56 ab	0.28 a	30.5 a	97 cd	247 bcd	75 abc
2 : 2 : 0	5.2 bc	0.57 bc	3.2 cd	0.83 bc	0.55 abc	0.20 bc	24.4 ab	105 bc	268 bc	81 ab
1 : 0 : 3	5.4 ab	0.60 ab	1.7 e	0.75 cd	0.42 de	0.19 bc	13.3 c	124 a	146 de	97 ab
1 : 1 : 2	5.4 ab	0.52 bc	4.0 bc	0.81 cd	0.43 de	0.23 ab	27.6 a	86 ef	174 de	77 abc
1 : 2 : 1	4.9 cd	0.69 a	4.4 ab	0.92 bc	0.38 ef	0.22 ab	25.4 ab	81 fg	185 de	71 abc
1 : 3 : 0	5.5 ab	0.57 abc	4.5 ab	1.15 a	0.56 ab	0.22 ab	21.1 bc	101 bcd	428 a	85 ab
0 : 0 : 4	5.9 a	0.34 d	2.1 e	0.65 e	0.27 f	0.16 d	15.5 c	128 a	99 e	39 d
0 : 1 : 3	4.5 de	0.49 c	3.1 cd	0.71 de	0.33 f	0.16 d	31.0 a	93 cd	91 e	57 cd
0 : 2 : 2	4.9 cd	0.42 c	4.8 a	0.66 e	0.47 cd	0.15 d	22.9 bc	81 fg	186 de	87 ab
0 : 3 : 1	4.3 e	0.64 a	5.1 a	0.75 cd	0.53 bc	0.15 d	21.3 bc	68 g	184 de	61 b
0 : 4 : 0	4.5 de	0.65 a	4.7 a	0.95 b	0.48 cd	0.19 bc	25.8 ab	87 ef	224 bcd	79 ab
Suggested range[x]	3.5−5.5	0.35−1.0	2.0−8.0	0.8−3.0	0.2−1.5	0.2−0.8	30−150	60−200	50−200	30−150

[z]PT: peat moss, CP: coco peat, PL: perlite.

[y]Mean separation within columns according to Duncan's multiple range test at the $p < 0.05$ level.

[x]Suggested ranges by JR Peters Inc. (Allentown, PA, USA) for general horticultural crops.

suggested range (0.2 − 0.8%). The content of boron was as high as 27.6 − 31.0 mg·kg^{-1} in leaf tissue grown in the media with mixing ratios of 0:1:3, 2:1:1 and 1:1:2 and was low in the media with mixing ratios of 4:0:0, 1:0:3 and 0:0:4 with high ratios of peat moss or perlite. The iron content was high in leaf tissue grown in the media with mixing ratios of 1:0:3 and 0:0:4 but was within the suggested range (60 − 200 mg·kg^{-1}) in all media types. The manganese content was highest at 428 mg·kg^{-1} in leaf tissue grown in the medium with a mixing ratio of 1:3:0 and it was at the lowest in media of mixing ratios of 0:1:3 and 0:0:4. The zinc content in leaf tissue was the lowest in the medium with 100% perlite, but it was within the suggested range (30 − 150 mg·kg^{-1}) in all media samples as well.

Discussion

The shoot growth, fresh weight and dry weight of New Zealand spinach were poor in media with mixing ratios of 0:0:4, 0:1:3, 0:2:2 and 1:0:3, which had higher ratios of perlite (Tables 1 and 2). Kim et al. (2011) reported that the plant height, number of branches, root length, fresh weight, and dry weight in New Zealand spinach were better in silt loam soil than in the sandy soil of the natural habitat of this plant, as the water- and nutrient-holding capacities of silt loam soil are higher than those of sandy soil. In this study, the medium of 100% perlite had the lowest water content (61.2%) and the highest bulk density (0.18 g·cm^{-3}) (Table 3). In general, when the bulk density of the soil is high, its water holding capacity is reduced due to the increased porosity (Hanan et al., 1981, Son and Cho, 2000). Therefore, it was judged that the poor

growth in the perlite medium was due to the easy drying of soil or the easy leaching of fertilizer components caused by the low water- and nutrient-holding capacities stemming from physical properties such as the low moisture content and high porosity of perlite (Yoo and Kang, 2005; Yoo et al., 2017).

These physical properties of perlite also affect its chemical properties. Son and Cho (2000) reported that the cation exchange capacity (CEC) of perlite was lower than that of vermiculite or rock wool. Also, Choi et al. (2007) reported that the higher the mixing ratio of perlite compared to peat moss or coco peat, the lower the EC and the higher the pH. In this study, the pH was as high as 6.2 − 6.9, and the contents of inorganic elements such as nitrate nitrogen, phosphorus, potassium, boron and iron as well as EC (0.09 − 0.16 $dS \cdot m^{-1}$) were lowest in the media with high mixing ratios of perlite (Table 4). As such, the low inorganic contents of the perlite medium also affected the contents of inorganic elements absorbed into the leaf such that the contents of phosphorus, potassium, calcium, magnesium, boron, manganese, and zinc of the leaves grown in media with high mixing ratios of perlite were lower than those in other media (Table 5). This explains the poor growth of New Zealand spinach in media with high mixing ratios of perlite.

The shoot growth and fresh and dry weights were poor in the 4:0:0 and 3:0:1 media composed of a high ratio of peat moss (Tables 1 and 2). In this study, the moisture contents and porosity levels were lower in the 4:0:0 and 3:0:1 media composed of a high ratio of peat moss than in the 1:3:0 and 0:4:0 media types composed of a high ratio of the coco peat. On the other hand, the moisture contents (68.0 − 73.7%) in the 4:0:0 and 3:0:1 media types were higher than in the perlite medium (61.2%) (Table 3). Peat moss has a higher moisture content than the perlite medium, and the higher the mixing ratio of peat moss to perlite, the higher the moisture content. The growth of okra (*Abelmoschus esculentus* L.) was most suitable in a 1:2 medium composed of peat moss and perlite, and it was reported that as the ratio of peat moss was increased, the moisture content became excessive and the plants withered (Kim and Kim, 2011; Lee et al., 2022).

The pH of the medium has a great effect on the absorption of nutrients by plants, and peat moss is known to be strongly acidic with a pH of 3 − 4. Moreover, when perlite is mixed with peat moss, the pH rises and EC decreases compared to a medium consisting of 100% peat moss (Shin et al., 2012; Shim et al., 2016). In this study, the media with a high mixing ratio of peat moss had lower pH levels and higher contents of inorganic components such as EC, NO_3-N, NH_4-N, phosphorus, calcium, magnesium, sulfur and iron compared to the 0:0:4, 0:1:3, and 1:0:3 media types composed of a high mixing ratio of perlite. The amounts of inorganic components in these types of media also affect the components in the leaf, meaning that leaves grown in media with a high mixing ratio of peat moss showed higher contents of inorganic components such as phosphoric acid, calcium, magnesium, and manganese than leaves grown in media with a high mixing ratio of perlite. On the other hand, they had a higher nitrogen content and lower potassium content than the leaves grown in media with a high mixing ratio of coco peat. Similar to results of this study, in an experiment involving a salvia medium, 2:1 and 3:1 media with a high mixing ratio of peat moss had higher EC and contents of inorganic components (NO_3-N, phosphorus, potassium, calcium, magnesium, sulfur, boron, iron, copper, and zinc) compared to a medium composed of 100% perlite (0:1) (Yoo et al., 2017). Also, it was reported that the shoot and root growth levels of salvia were effective in media composed of a high mixing ratio peat moss, and the results of an analysis of the nutrient components of salvia leaves were similar to those in this study (Yoo et al., 2017). Even in the case of New Zealand spinach in this study, the 2:0:2 medium composed of 50% peat moss and 50% perlite showed better shoot and root growth than media composed of 100% peat moss or perlite.

Coco peat has high water- and nutrient-holding capacities, similar to those of peat moss, but has higher porosity and a

higher air phase ratio than peat moss, giving it good air permeability (Shin et al., 2012). It was reported that New Zealand spinach has grown in clay layers mixed with sand and exposed to periodic flooding, such as sand dunes, swales, creeks and claypans in Australia, which means that New Zealand spinach grows in soil conditions with high water contents and good air permeability (Gray, 1997; Kim et al., 2012). In this study, the air phase ratio, porosity, and moisture content of the coco peat medium (0:4:0) were higher than those of media composed of peat moss and perlite, at 57.4%, 62.8% and 82.2%, respectively. Compared to the media (4:0:0, 3:1:0, and 3:0:1) with a high mixing ratio of peat moss, the media (0:4:0, 0:3:1, and 1:3:0) with a high mixing ratio of coco peat showed higher contents of potassium and boron, and the pH (5.0 − 6.0) was more suitable for the growth of New Zealand spinach (Kim et al., 2011). In general, when the soil pH is lower than 4.5, such as that in media with a high mixing ratio of peat moss, the uptake of macro-elements into the leaves is inhibited (Yi et al., 2013). With regard to New Zealand spinach, the potassium content of the leaves grown in the media with a high mixing ratio of coco peat was significantly higher than those in the media with a high mixing ratio of peat moss. For this reason, it was judged that the growth of New Zealand spinach was better in media with a high mixing ratio of coco peat than in media with a high mixing ratio of peat moss.

Among the media (1:3:0, 0:3:1, and 0:4:0) types with a high mixing ratio of coco peat, the 1:3:0 medium showed higher porosity (64.9%) in terms of the physical properties and the highest EC (0.93 $dS \cdot m^{-1}$) and NO_3-N (38.3 $mg \cdot kg^{-1}$), phosphorus (11.7 $mg \cdot kg^{-1}$), potassium (179.9 $mg \cdot kg^{-1}$), sulfur (7.8 $mg \cdot kg^{-1}$), and zinc (0.07 $mg \cdot kg^{-1}$) contents in terms of chemical properties. Also, the contents of the nutritional components in the leaves, such as nitrogen (5.5%), calcium (1.15%), magnesium (0.56%), iron (101 $mg \cdot kg^{-1}$), and manganese (428 $mg \cdot kg^{-1}$), were higher in the 1:3:0 medium than in the 0:3:1 and 0:4:0 media types. These results are similar to those from several studies that reported that plants were able to absorb more nutrients when the inorganic element contents in the medium were high. For the Asiatic lily 'Orange Pixie', it was reported that the leaves of plants grown in a medium with high phosphorus and potassium contents had high phosphorus and potassium contents. Also, in the strawberry 'Seolhyang', the potassium content in the plant was said to be high when grown in coco peat medium, which has a high potassium content (Choi et al., 2002; Choi et al., 2011). Therefore, in this study, due to the better physical properties, higher contents of inorganic components and higher nutrient contents of leaves grown in the 1:3:0 medium, it was judged that the growth of New Zealand spinach in the 1:3:0 medium exceeded those from the other media types tested here.

Conclusion

In this study, we investigated the growth of shoots and roots according to the mixing ratios of peat moss, coco peat, and perlite to develop the most suitable medium for the cultivation of New Zealand spinach in a greenhouse. The medium \with a mixing ratio of 1:3:0 with peat moss, coco peat, and perlite showed higher porosity as well as higher EC, and NO_3-N, phosphorus, potassium, sulfur and zinc contents in terms of the physicochemical properties. Also, the contents of the nutritional components in the leaves, in this case nitrogen, calcium, magnesium, iron and manganese, were higher in the 1:3:0 medium than in the other media types tested here. As such, it was judged that the shoot and root growth of New Zealand spinach was excellent due to the high nutrient contents of the leaves and the good physicochemical properties of the 1:3:0 medium. Therefore, the medium with a mixing ratio of 1:3:0 with peat moss, coco peat, and perlite is recommended for use to grow New Zealand spinach.

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